63-3-2

401 381

Research Note

Dispersion of Rayleigh Waves Along the Mid-Atlantic Ridge

HENRY A. OSSING

Research Note

Dispersion of Rayleigh Waves Along the Mid-Atlantic Ridge

HENRY A. OSSING

Abstract

Comparison of the characteristic dispersion curves of Rayleigh waves from earthquakes occurring in five sections of the Mid-Atlantic Ridge, whose travel paths to Weston include basin and basin plus ridge paths, is made with a theoretical curve taken from Dorman's Case 8099 and Dorman and Oliver's Case 8341 to determine the effect of the Ridge on the dispersion of Rayleigh waves. Small increments of variations between the averaged dispersion curves traversing only basin paths and those traversing basin and ridge paths in the significant period range 18 - 25 seconds are suggestive but not conclusive. Thus the investigation of events having longer ridge travel paths is necessary.

iii

Dispersion of Rayleigh Waves
Along the Mid-Atlantic Ridge

1. INTRODUCTION

The basic structure underlying the oceans of the earth has been determined primarily by applying seismic surface wave dispersion methods to various earthquakes whose epicenter-to-station paths are oceanic. The dispersion of these surface waves provides general information of the substructure in a regional sense covering oceanic dimensions, and has been complemented by seismic refraction techniques that provide detailed information over limited areas. The dispersion of surface waves traversing deep oceanic paths has been found to be uniform throughout the world; that is, the surface waves travel with nearly the same group velocities at corresponding periods independent of the particular ocean basin considered. Minor variations of group velocity with respect to period do occur and can be usually attributed to variations in water depth or inclusion of small segments of nonoceanic path.

The effect of major structural relief, such as the Mid-Atlantic Ridge, on the dispersion characteristics of Rayleigh waves along oceanic paths will be discussed. While the study is divided into two phases, this report deals only with the results of the first phase. The two phases are as follows: 1) the effect of the Mid-Atlantic Ridge on surface waves originating from sources whose epicenters are located in or near the vicinity of the Ridge in the areas bounded by 25°N-10°S lat and by 10°W-50°W long. (Figure 1) and recorded at Weston Observatory. The earthquakes examined include those whose surface waves traverse only the western

Atlantic basin, encountering no major structural relief outside of the continental shelf, and those whose great circle travel paths include a 10 percent segment of the Ridge from source to station; (2) the second phase will consider the dispersion of surface waves from those earthquakes whose epicenters are again in the vicinity of the Mid-Atlantic Ridge within the boundaries 20°N-10°S lat. and 10°W-50°W long. but were recorded in the Caribbean area. As in the first phase, the travel paths will include only basin paths crossing no important structural relief, and those earthquakes 60 percent of whose great circle travel paths lie along the Mid-Atlantic Ridge. No continental correction will be applied to the first phase due to the small portion of continental path traversed by the surface waves (<4 percent).
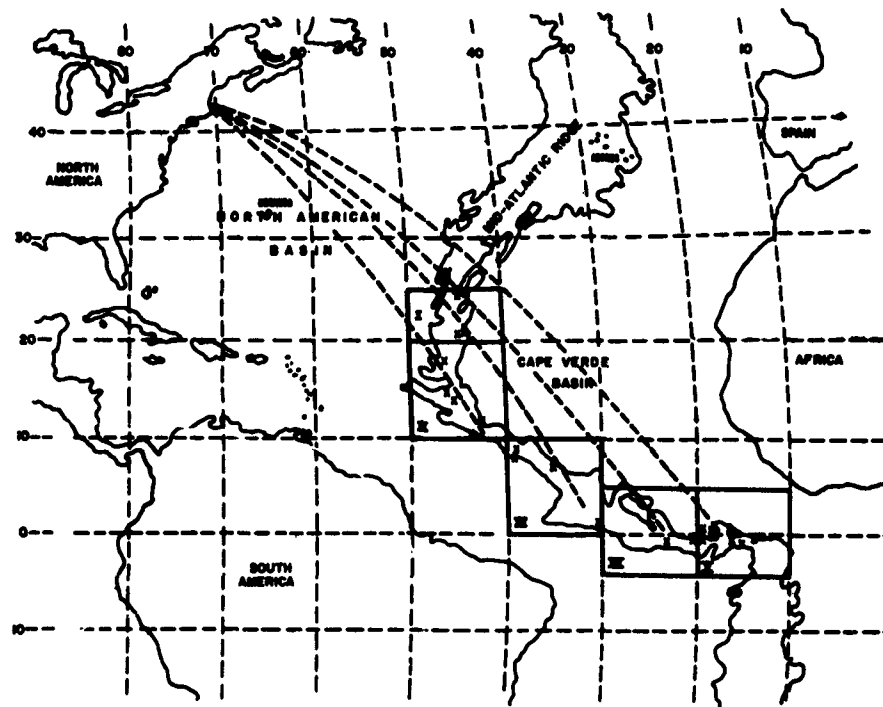

Figure 1. Great Circle Travel Paths for Earthquakes Occurring in Sections I-V

2. PHYSIOGRAPHY AND STRUCTURE

The Mid-Atlantic Ridge, a system of mountains, plateaus, rift valleys, and trenches, forms a continuous structural relief bisecting the North and South Atlantic

Oceans from Iceland to the Atlantic Indian Rise where it joins the Madagascar Ridge some 7000 km south of the Cape of Good Hope. Following the continental profiles of both the Americas, Europe and Africa, the Mid-Atlantic Ridge is 1500 to 2000 km in width and rises to less than 2000 fathoms in depth from the surface with a crustal thickness up to 30 km.[1]

The Mid-Atlantic Ridge has been divided into the crest and flank provinces:[2]

1)   The crest province consists of a high fractured plateau, lateral rift mountains rising to elevations greater than 1000 fathoms above the ocean floor, and a rift valley. The width of the crest province is 100 - 200 km with the majority of the earthquakes, almost all shallow focus, occurring in the rift valley which traverses the entire length of the ridge.

2)   The flank province consists of a series of tilted blocks in ascending step-like plateaus commencing at the ocean basin and terminating at the fractured plateau level of the crest province. Structural detail of the flank provinces is scarce compared to that of the crest province where gravity, magnetic, seismic, and heat flow measurements have been obtained in some quantity.

Gravity observations show that the ridge is in nearly isostatic equilibrium with almost zero isostatic anomaly around the equator,[3] the area of the ridge under consideration in this study. Although there is a large diversity of anomalies locally, this is considerably reduced when regional isostatic reductions are made. Thus regionally, the ridge is nearly compensated with a slight tendency to be anomalous on the positive side. Talwani[1] concludes that this compensation must take place at a depth less than 25 km and postulates a layer of low velocity and density some 15 km thick underlying a layer of high velocity and density approximately 3 km thick. This theory would provide crustal instability required for forming the rift valley and at the same time, explain the shallow seismicity associated with the rift valley.

Magnetic observations of the Mid-Atlantic Ridge near 30°N-40°W revealed a large distinctive anomaly of 200 - 700 gammas associated with the rift valley.[4] It was shown that this anomaly was not due to fault or relief structure but to a highly magnetized subsurface body. Talwani[1] suggests that the proposed low density layer is the highly magnetized layer surrounded by high density material that forces the low density layer upward and causes the temperature of the layer to drop below the Curie point for the minerals involved. Thus a highly magnetized layer of low density is produced. Seismic refraction techniques would be unable to detect such a layer, but possibly dispersion studies could indicate departures from the normal over the period range affected by a low density layer of sufficient thickness. This departure from normalcy would be most evident in the 18-25 sec period range whose dispersive characteristics are influenced primarily by the elastic constants of the crustal layer and its thickness.

3. OCEANIC RAYLEIGH WAVES

Long period Rayleigh wave trains as identified on seismograms fall into two categories: (1) those having continental characteristics; (2) those having oceanic characteristics. The dispersion of Rayleigh waves traversing continental paths is weak compared to those following ocean paths; that is, the frequency component of a pulse becomes separated in time over a shorter travel path in the oceanic case, than in the continental case. The essential difference in their dispersion curves is that the continental group velocity curves have a maximum group velocity near 3.7 km/sec at periods around 70 sec and a minimum group velocity of about 3.0 km/sec around periods of 20 sec. On the other hand, oceanic Rayleigh wave dispersion curves have a maximum group velocity near 4.0 km/sec at periods close to 40 sec and a minimum of 1.0 km/sec near periods of 14 sec. For periods greater than 100 sec there is no appreciable difference in the dispersion curves since, in both cases, the longer waves are controlled by the properties of the mantle.

Ewing and Press[5] showed that the combined water and sedimentary layer controls the dispersion of periods 14-18 sec. Their conclusion was based on the fact that both their theoretical and observed dispersion curves have group velocities whose periods approach the speed of sound in water rather than approximately twice this value as with continental waves of similar periods. Oceanic Rayleigh waves of periods less than 14 sec are rarely recorded for reasons not completely understood. Phinney[6] advances the theory that scattering by inhomogeneities or variations in crustal thickness as a plausible explanation for this phenomenon. For Rayleigh waves of periods 18 - 25 sec, the principal dispersive influence is the crustal parameters and the thickness of the layer. The longer period waves are affected by the transition from crustal to mantle properties up to periods of 70 sec which is the short wave limit from mantle propagation. In other words, waves over 70 sec are not significantly influenced by major discontinuities and boundaries, but are affected by the shear velocity gradient of the mantle.

The theoretical model used in comparing the observed dispersion curves is taken from Case 8341 of Oliver and Dorman[7] for periods below 25 sec, and from Case 8099 of Dorman[8] for periods 25 sec and above. These two models were chosen as representative of a multilayered ocean in their respective period ranges and combined to form one theoretical curve.

4. EXPERIMENTAL METHOD

The procedure followed in reading the dispersed wave train from seismograms recorded by vertical instruments is taken from the method employed by Ewing and Press.[9] Consecutive numbers are assigned to zero amplitude points commencing

with the earliest observable Rayleigh wave and continuing to the end of the wave train. Each number and its corresponding arrival time are plotted, and the slope of the resulting curve yields the period for any point on the curve. The group velocity for each period is then easily calculated and plotted against its corresponding period.

The seismograms used were recorded at Weston Observatory by a Benioff vertical ($T_o = 1$, $T_g = 60$ sec) and a long period vertical Sprengnether ($T_o = 30$, $T_g = 100$ sec). The error in group velocity of the periods of interest due to instrumental phase shift can be neglected, since the largest error is less than 03 km/sec for all paths considered.

The epicentral location for the earthquakes in Table 1 was taken from the U. S. Coast and Geodetic Survey preliminary epicentral determination cards and from Gutenburg and Richter. [10] All of the shocks considered are shallow focus (h=25 km) with no magnitudes exceeding $7\frac{1}{4}$.

5. EXPERIMENTAL AND THEORETICAL COMPARISONS

Dispersion curves were obtained for each of the events in Table I and plotted according to their respective sections. Figure 2 compares the theoretical curve from Cases 8341 and 8099 with the average dispersion of Rayleigh waves traversing basin paths which were taken from Sections I and II (henceforth referred to as Group I).

Figure 3 shows the average dispersion of Rayleigh waves for the events in Sections III, IV and V (henceforth referred to as Group II). This figure represents travel paths including portions of the Mid-Atlantic Ridge.

The averaged experimental data from Sections I and II are presented in Figure 2; those from Sections III, IV and V are presented in Figure 3. The resulting data plotted in Figure 4 shows the average dispersion of those events whose surface waves traverse only basin paths (Group I), and the average of those whose surface waves follow portions of the Ridge (Group II).

It is evident from Figures 2 and 3 that the dispersion of the measured Rayleigh waves is of an oceanic character for both Groups I and II. The group velocity for both groups falls above the theoretical for periods less than 25 sec. This would suggest a basement layer of increasing thickness influencing the group velocities in the period range 18-25 sec. For periods less than 18 sec, the group velocity is affected by the depth of the sedimentary layer; the degree of deviation from the theoretical being approximately the same amount for both groups would indicate no appreciable amount of variation between the average sedimentary depths along the paths traversed by Groups I and II. The group velocities of periods over 25 sec fit

TABLE 1. Epicentral Locations

Section	No.	Date	GCT	Lat	Long.	Mag	km
I	1	13 Dec 1937	22 58 47	26°N	45°W	6	3010
	2	6 May 1944	00 13 42	22°N	44°W	$6\frac{1}{4}$	3400
	3	5 Feb 1957	04 51 20	25.5°N	45.5°W		3165
	4	3 Jun 1962	15 02 25.5	22.4°N	45.2°W		3290
II	1	31 Dec 1942	12 03 42	18°N	47°W	$6\frac{1}{2}$	3545
	2	1 Dec 1950	14 50 58	14°N	47.4°W	$7\frac{1}{4}$	3910
	3	18 Oct 1952	11 57 36	13°N	46°W		4080
	4	20 Oct 1957	12 04 22	11.5°N	42°W		4455
	5	17 Mar 1962	20 47 31.7	10.6°N	43.7°W		4445
III	1	27 Nov 1942	10 38 45	7.5°N	36°W	7	5190
	2	24 Apr 1947	19 35 14	8.5°N	39°W	7	4910
	3	9 Mar 1954	02 21 43	1.5°N	30.5°W		6090
	4	25 Sep 1958	07 20 02	9°N	39.9°W	$6\frac{1}{2}$	4835
IV	1	6 Aug 1954	16 19 45	1°S	23.5°W		6790
	2	4 Feb 1962	21 29 33	0.5°S	20.3°W		6973
V	1	23 Apr 1939	16 23 06	0.5°N	17.5°W	$6\frac{1}{4}$	7090
	2	27 Apr 1940	10 33 13	1°N	19.5°W	$6\frac{3}{4}$	6900
	3	13 Apr 1942	07 46 18	1°S	16°W	6	7320
	4	19 Feb 1953	15 17 40	0°	18°W		7090
	5	11 Jul 1955	20 21 20	1.5°S	13°W		7465
	6	3 Sep 1958	03 44 24	0°	18°W		7090
	7	26 Mar 1962	12 04 54.6	0.5°S	19.2°W		7045
	8	17 Apr 1962	22 34 56.7	1.5°S	14.9°W		7445

the theoretical curve very well. From the above results, it appears that a better approximation of the crustal parameters for the dispersion of periods in the intermediate range is given in Dorman's Case 8099 than in Oliver and Dorman's Case 8341 for the dispersion in the short period range.

The observed data of Groups I and II are averaged and plotted in Figure 4. The difference is slight, but appears not to be entirely random. There is excellent agreement in group velocity for periods of 15-17 sec as previously noted, but after 17 sec, the Group II curve begins to fall below the curve for Group I with increasing divergence with increasing period. This divergence continues until, at periods

of 25 sec, the variation tends to level off. The dispersion data for periods greater than 25 sec is limited when compared with the data for the shorter periods, yet there are data to suggest a leveling point around 25 sec where the variation remains the same for increasing periods.

Although the above variation between Groups I and II may not be statistically significant, it is of interest to note that the variation occurs in the period range whose group velocities are controlled mainly by the parameters of the basement layer. Thus, the extended wavepath of Group II (the Ridge) could be an influencing factor. If this is the case, then it should be more evident for those waves whose travel paths include a more sizable portion of the Ridge. (Phase II of this study is a consideration of this aspect.)
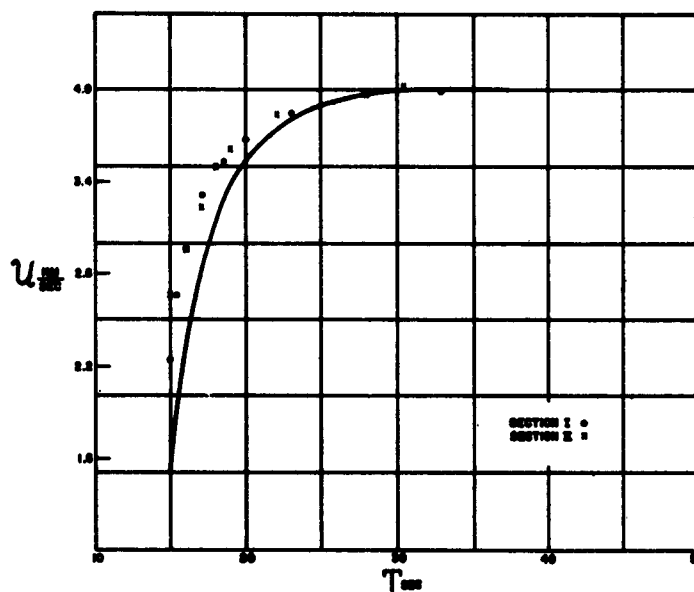

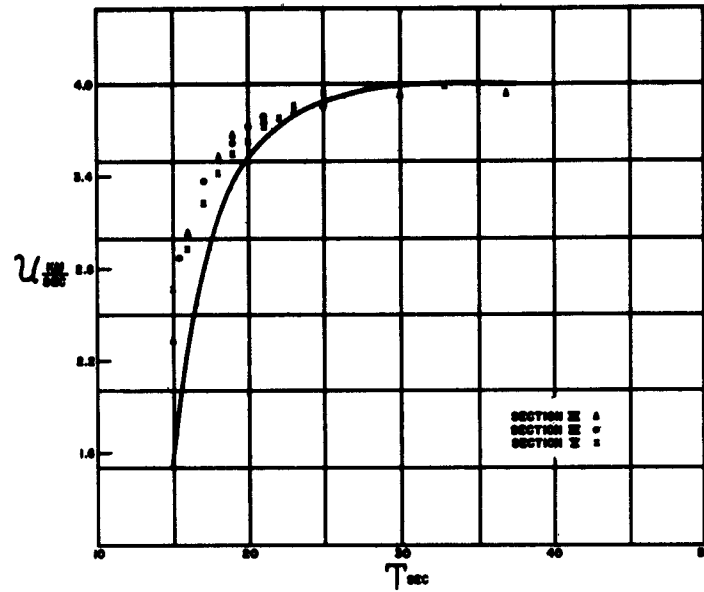Figure 2. Averaged Dispersion Curves for Sections I-II (Group I)

8

Figure 3. Averaged Dispersion Curves for Sections III, IV, V (Group II)
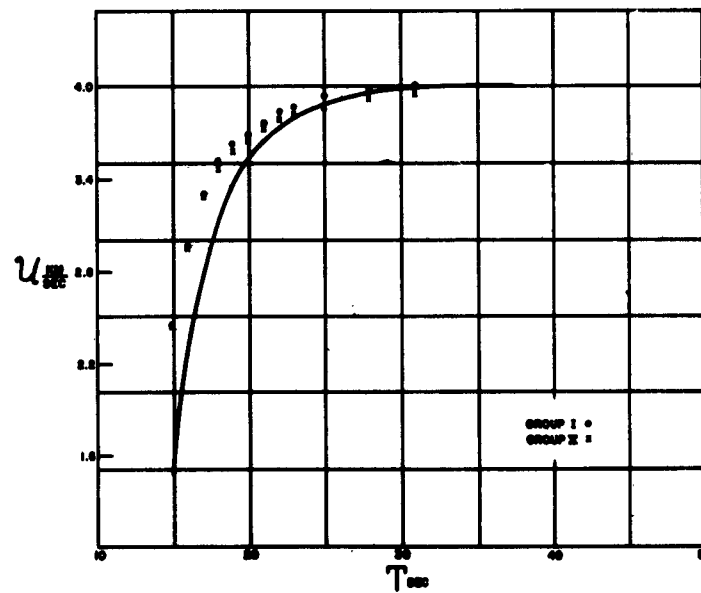

Figure 4. Averaged Dispersion Curves for Groups I-II

References

1. Talwani, M., Heezen, B., Worzel, J., "Gravity Anomalies, Physiography and Structure of the Mid-Atlantic Ridge," Lamont Geological Observatory Contribution No. 474, 1961, 30 pp.

2. Heezen, B., Thorp, M., Ewing, M., "The Floor of the Ocean, 1. The North Atlantic," Geo. Soc. of Amer., Sp. Paper 65, 1959, 122 pp.

3. Ewing, M., "The Atlantic Basin," Bull. of the Amer. Mus. of Nat. Hist., 99, 1952, pp. 87-91.

4. Ewing, M., Hirshman, J., Heezen, B., "Magnetic Anomalies of the Mid-Oceanic Rift," Intl. Oceanogr., Confer. Amer. Assoc. Adv. of Sci., 1959, pp. 24-25.

5. Ewing, M., Press, F., "Crustal Structure and Surface Wave Dispersion," B.S.S.A., 40, 1950, pp. 271-280.

6. Phinney, R. A., "Leaking Modes in the Crustal Wave Guide: The Oceanic PL-Wave," Jour. Geophys. Res., 66, 1961, pp. 1445-1469.

7. Oliver, J., Dorman, J., "On the Nature of Oceanic Seismic Surface Waves with Predominant Periods of 6 to 8 seconds," B.S.S.A., 51, 1961, pp. 437-455.

8. Dorman, J., Ewing, M., Oliver, J., "Study of the Shear-Velocity Distribution in the Upper Mantle of Rayleigh Waves," B.S.S.A., 50, 1960, pp. 87-115.

9. Ewing, M., Press, F., "Crustal Structure and Surface Wave Dispersion," Part II: B.S.S.A., 42, 1952, pp. 315-325.

10. Gutenburg, B., Richter, C., Seismicity of the Earth and Associated Phenomena, Princeton University Press, 1954, 310 pp.

AF Cambridge Research Laboratories, Bedford,
Mass. Geophysics Research Directorate
DISPERSION OF RAYLEIGH WAVES ALONG THE
MID-ATLANTIC RIDGE by H.A. Ossing, Jan 1963.
9 pp. incl. illus., table.   AFCRL-63-201
                Unclassified Report

Comparison of the characteristic dispersion curves
of Rayleigh waves from earthquakes occurring in
five sections of the Mid-Atlantic Ridge, whose
travel paths to Weston include basin and basin plus
ridge paths, is made with a theoretical curve taken
from Dorman's Case 8099 and Dorman and Oliver's
Case 8341 to determine the effect of the Ridge on
the dispersion of Rayleigh waves. Small increments
of variations between the averaged dispersion
curves traversing only basin paths and those trav-
ersing basin and ridge paths in the significant
period range 18-25 sec are suggestive but not con-
clusive. Thus the investigation of events having
longer ridge travel paths is necessary.

1. Seismology
2. Earthquakes
3. Oceanography

I. Ossing, H.A.

AF Cambridge Research Laboratories, Bedford,
Mass. Geophysics Research Directorate
DISPERSION OF RAYLEIGH WAVES ALONG THE
MID-ATLANTIC RIDGE by H.A. Ossing, Jan 1963.
9 pp. incl. illus., table.   AFCRL-63-201
                Unclassified Report

Comparison of the characteristic dispersion curves
of Rayleigh waves from earthquakes occurring in
five sections of the Mid-Atlantic Ridge, whose
travel paths to Weston include basin and basin plus
ridge paths, is made with a theoretical curve taken
from Dorman's Case 8099 and Dorman and Oliver's
Case 8341 to determine the effect of the Ridge on
the dispersion of Rayleigh waves. Small increments
of variations between the averaged dispersion
curves traversing only basin paths and those trav-
ersing basin and ridge paths in the significant
period range 18-25 sec are suggestive but not con-
clusive. Thus the investigation of events having
longer ridge travel paths is necessary.

1. Seismology
2. Earthquakes
3. Oceanography

I. Ossing, H.A.